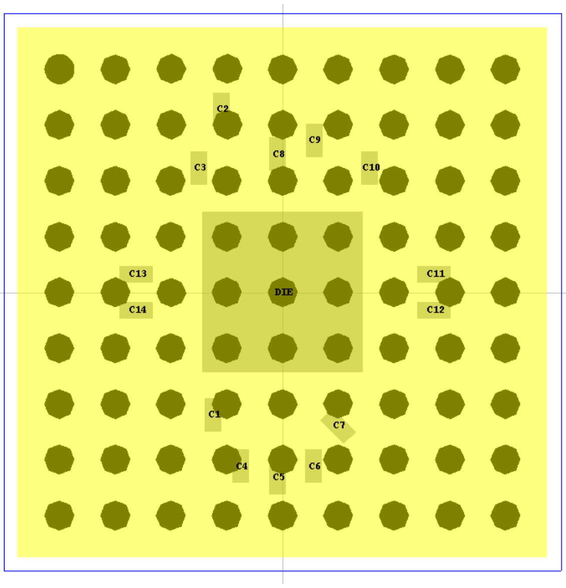
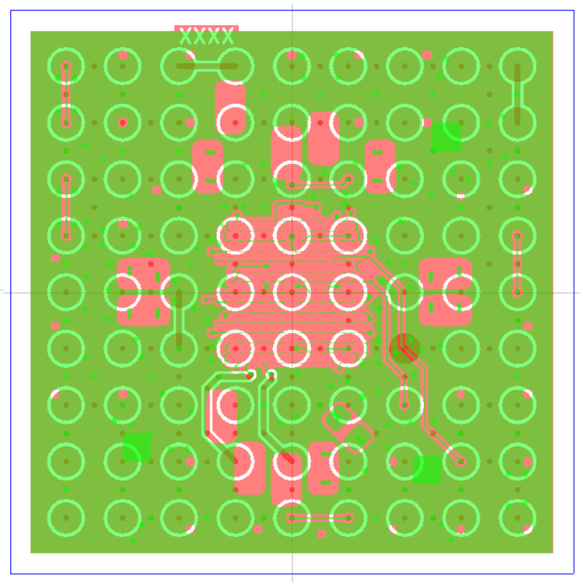
Performing a Solder Fatigue Analysis with Sherlock and ANSYS Workbench is Fun!

Gil Sharon, Nathan Blattau and Tyler Ferris
gsharon@dfrsolutions.com

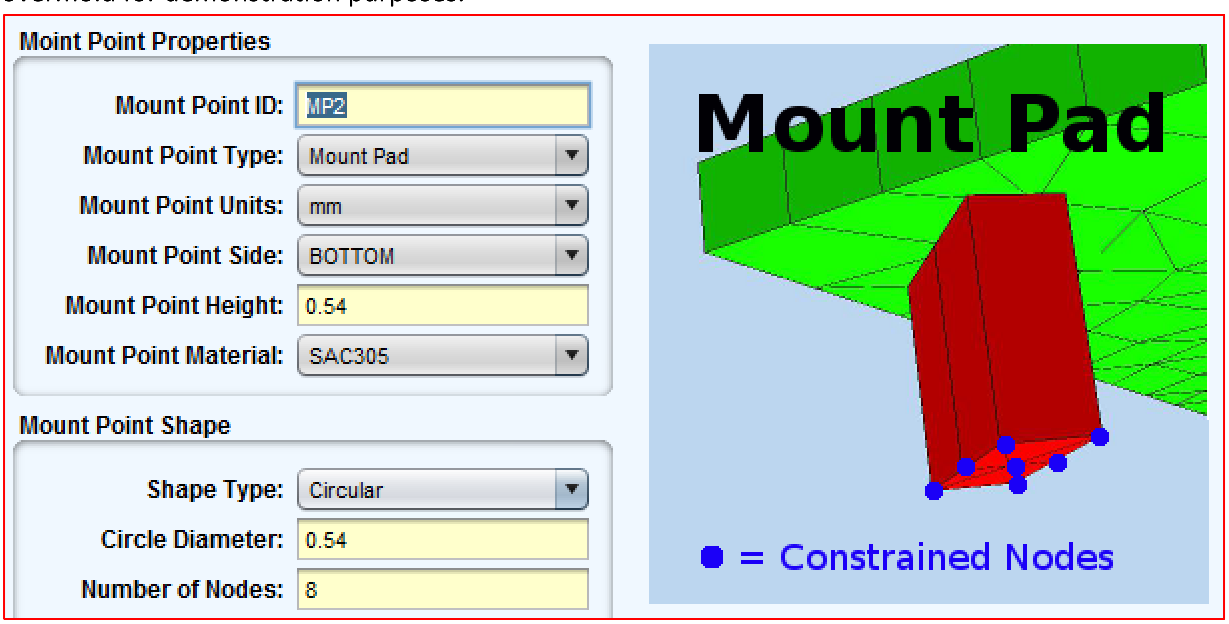
This is a step by step guide to performing a solder fatigue analysis of BGA balls loaded in shear due to temperature cycling.

1. Make the BGA model in Sherlock
   Import the ODB++ files for the BGA and the board in to Sherlock



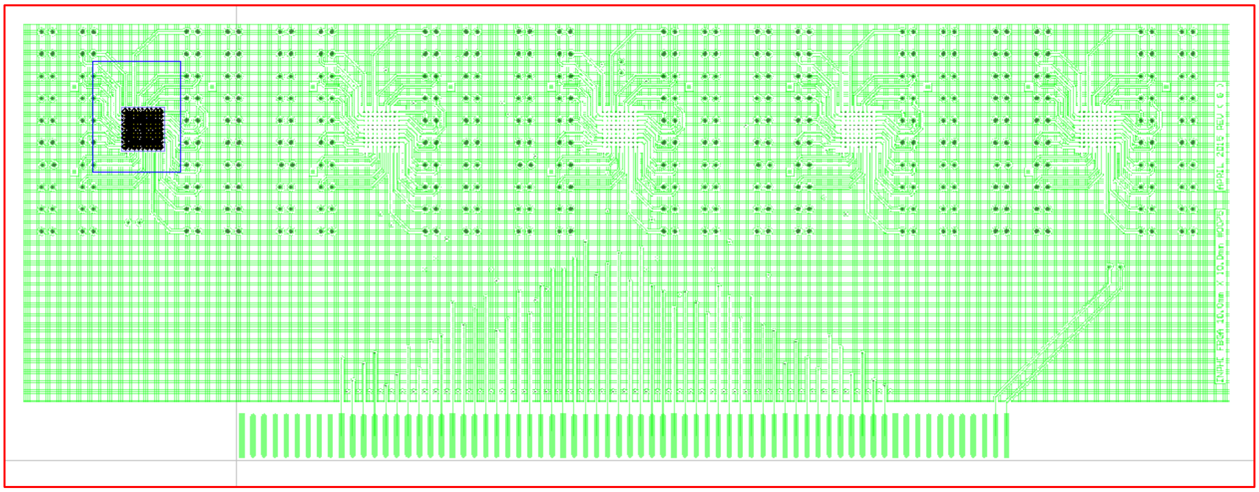


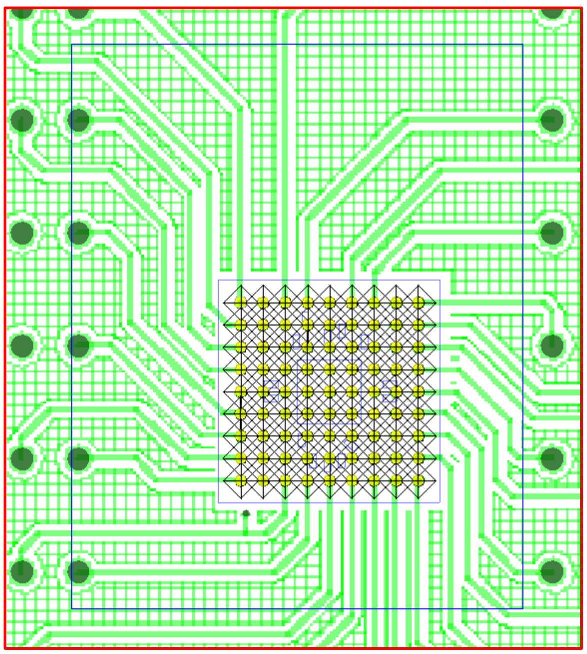
The black dots are mount pads. The yellow area is the BGA epoxy overmold material. The blue line is the package outline. There is a die with several passive capacitors encased in the overmold for demonstration purposes.



The mount point height is the solder ball thickness. The number of nodes can be set to 8 for most of the solder balls. It would probably be more beneficial to set the number of nodes to 20-

30 for any ball that is intended to be modeled in detail in Abaqus. In this example, one of the corner balls is selected.

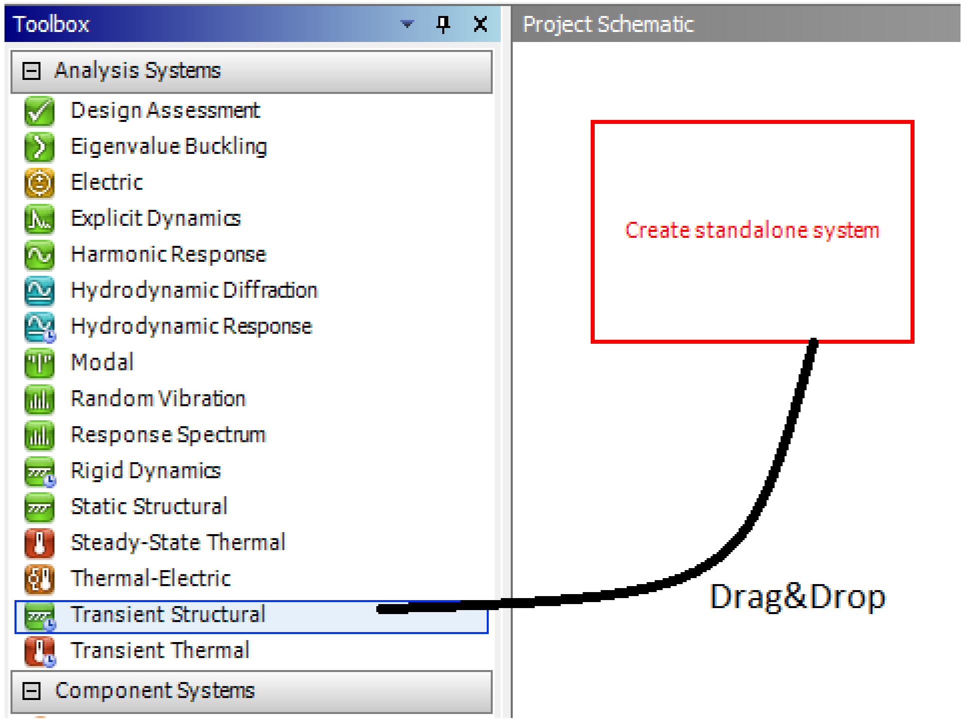




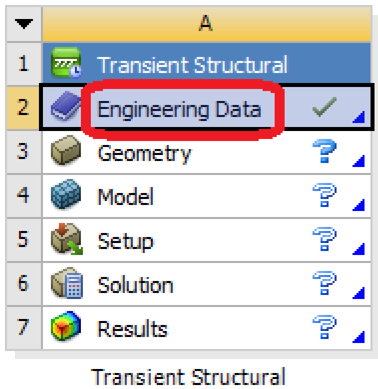
The BGA is assembled on to the board. The board outline is adjusted because we don't need to model the whole board. An area of the board is sufficient for solder fatigue modeling purposes. It is possible to export the whole board in some cases like overconstrained boards or components that are close to mount points.

2. Export the FEA model as a **STEP** file from Sherlock.

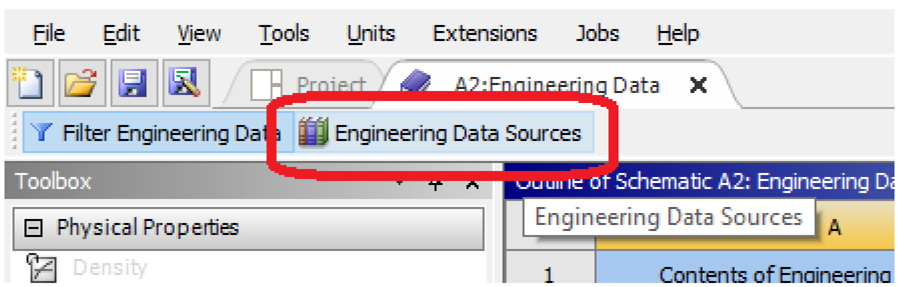
3. Open ANSYS Workbench
4. Drag a **"Transient Structural"** analysis system to the Project Schematic



5. Import the Solder material SAC305.xml
    a. Double Click **"Engineering Data"**

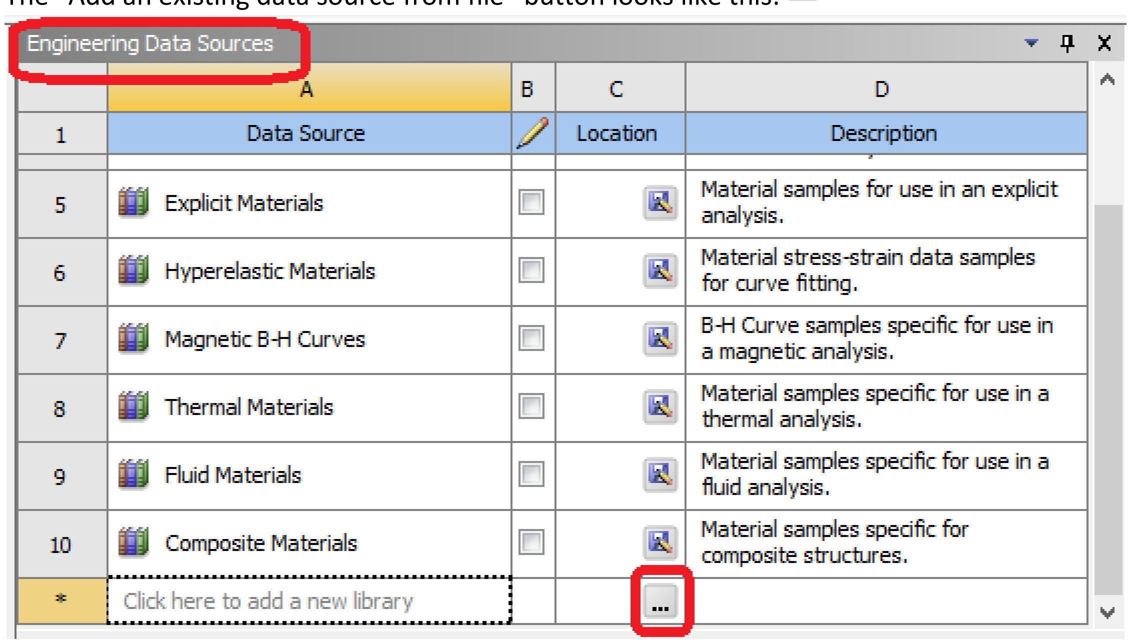


    b. Click **"Engineering Data Sources"** on the top left menu

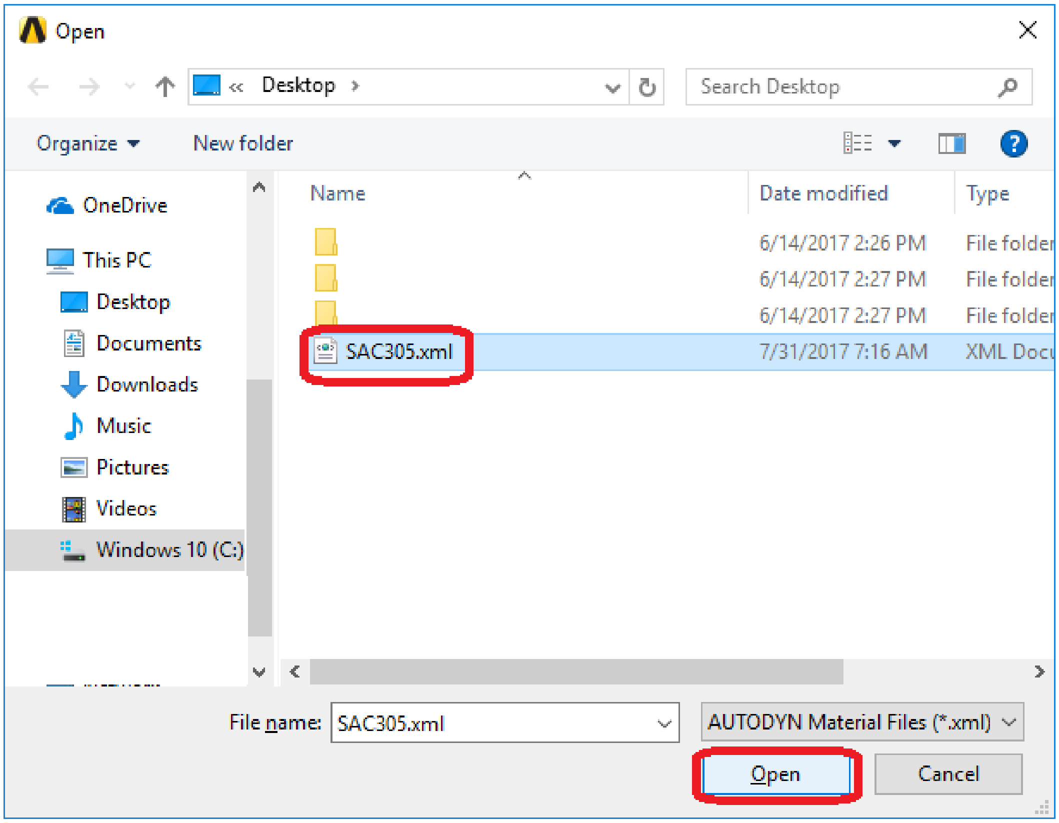


    c. Click on the **"Add an existing data source from file"** button next to the "Click here to add a new library" in the "Engineering Data Sources" window

The "Add an existing data source from file" button looks like this: 

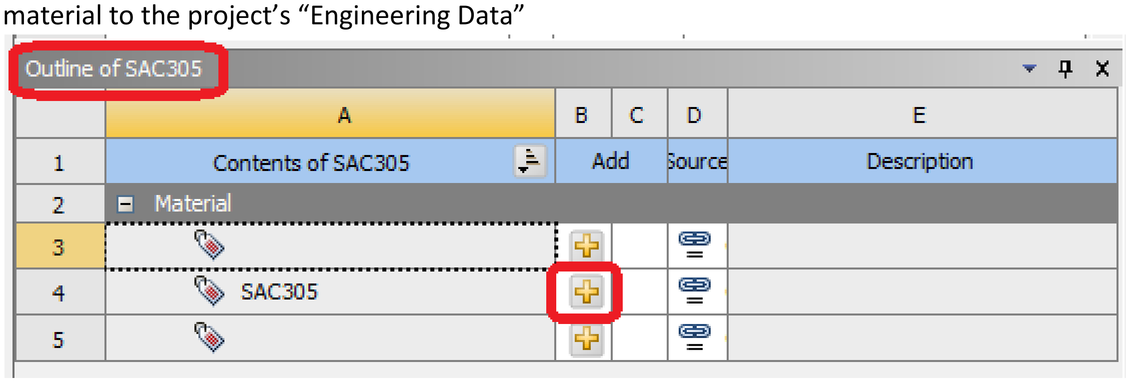


d. Browse to the SAC305.xml file and click **Open**

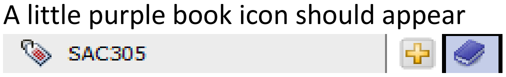


The "**FILE.xml"** material file can be downloaded from:
https://archive.org/download/Solders
Right click on **"Solders.xml">Save Link As…**
This file contains the ANSYS material inputs for SAC305 and eutectic 63Sn37Pb. Verify these properties before using.

e. In the "Outline of SAC305" window click the plus button next to SAC305 to add the material to the project's "Engineering Data"



A little purple book icon should appear

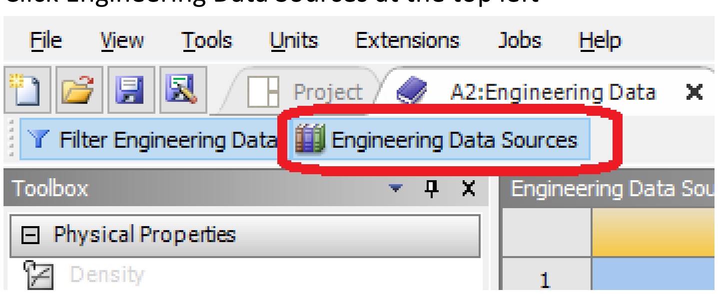


f. Clicking on this icon will show the properties in the "Properties of Outline Row: SAC305" Window

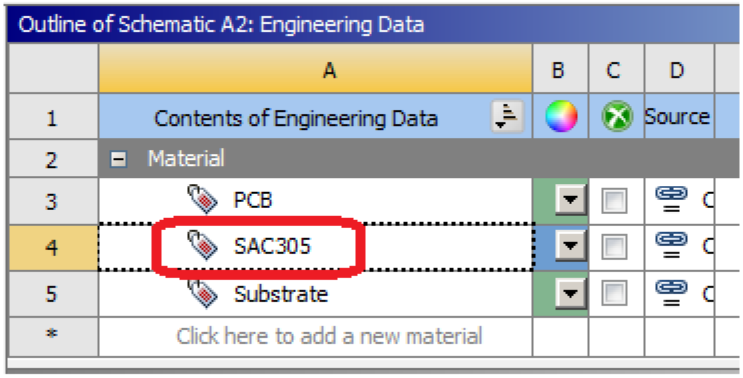
Properties of Outline Row 4: SAC305

	A	B	C
1	Property	Value	Unit
2	Density	7.38E-06	kg mm^-3
3	Isotropic Instantaneous Coefficient of Thermal Expansion	2.35E-05	C^-1
4	Isotropic Elasticity		
5	Derive from	Young's Modulus and Poisson's Ratio	
6	Young's Modulus	51000	MPa
7	Poisson's Ratio	0.36	
8	Bulk Modulus	60714	MPa
9	Shear Modulus	18750	MPa
10	Anand Viscoplasticity		
11	Reference Units (Stress, Temperature, Per Time)	MPa, K, s^-1	
12	Initial Deformation Resistance So	2.15	
13	Activation Energy Q/Universal Gas Constant R	9970	
14	Pre-exponential Factor A	17.994	
15	Multiplier of Stress ξ	0.35	
16	Strain Rate Sensitivity of Stress m	0.153	
17	Hardening/Softening Constant ho	1526	
18	Coefficient for Deformation Resistance Saturation Ŝ	2.536	
19	Strain Rate Sensitivity of Saturation (Deformation Resistance) n	0.028	
20	Strain Rate Sensitivity of Hardening or Softening a	1.69	

g. Click Engineering Data Sources at the top left

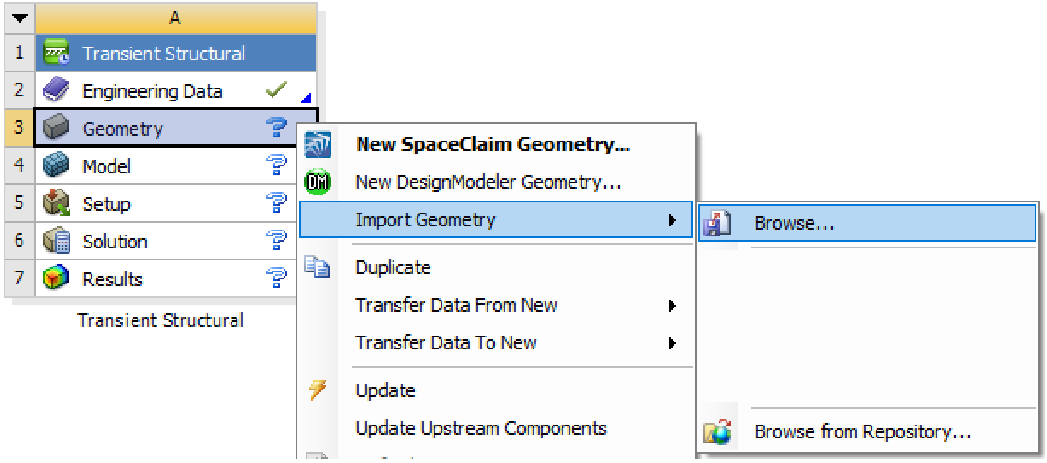


h. The “Outline of Schematic: Engineering Data” window should now have a SAC305 entry

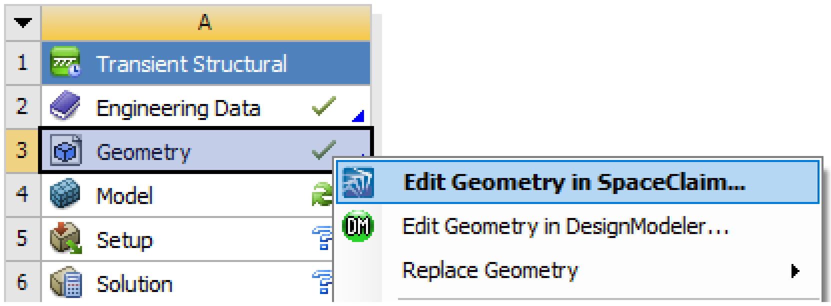


i. Close the “Engineering Data” tab

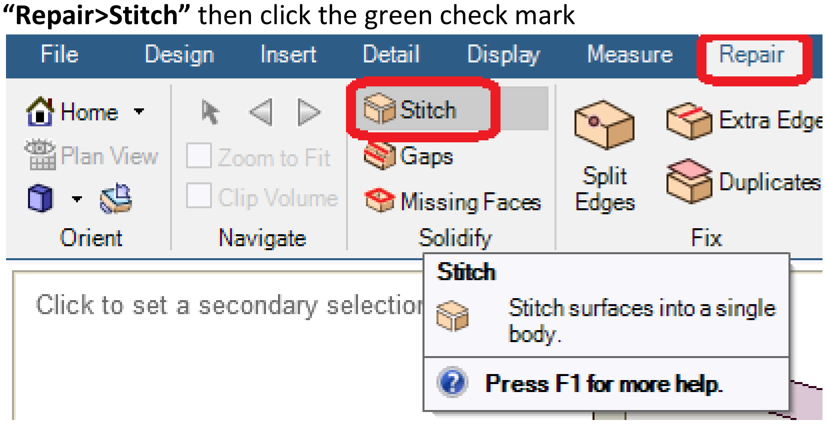
6. Import the Sherlock created geometry to ANSYS Workbench
   a. Right Click **"Geometry>Import Geometry>Browse"**



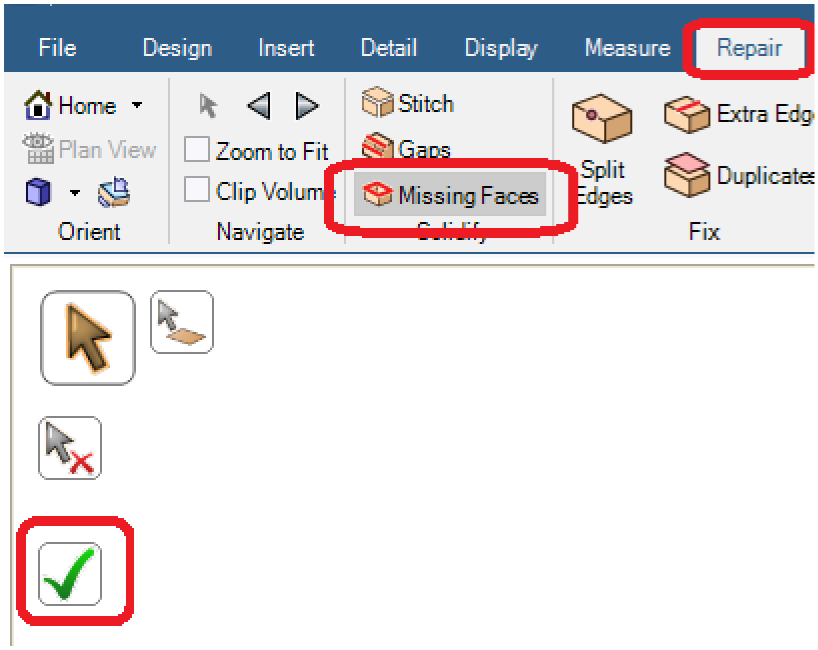
   b. Select the **FILE.stp** for the BGA and click **"Open"**
   c. Right click "**Geometry>Edit Geometry in SpaceClaim…**"



   d. **"Repair>Stitch"** then click the green check mark

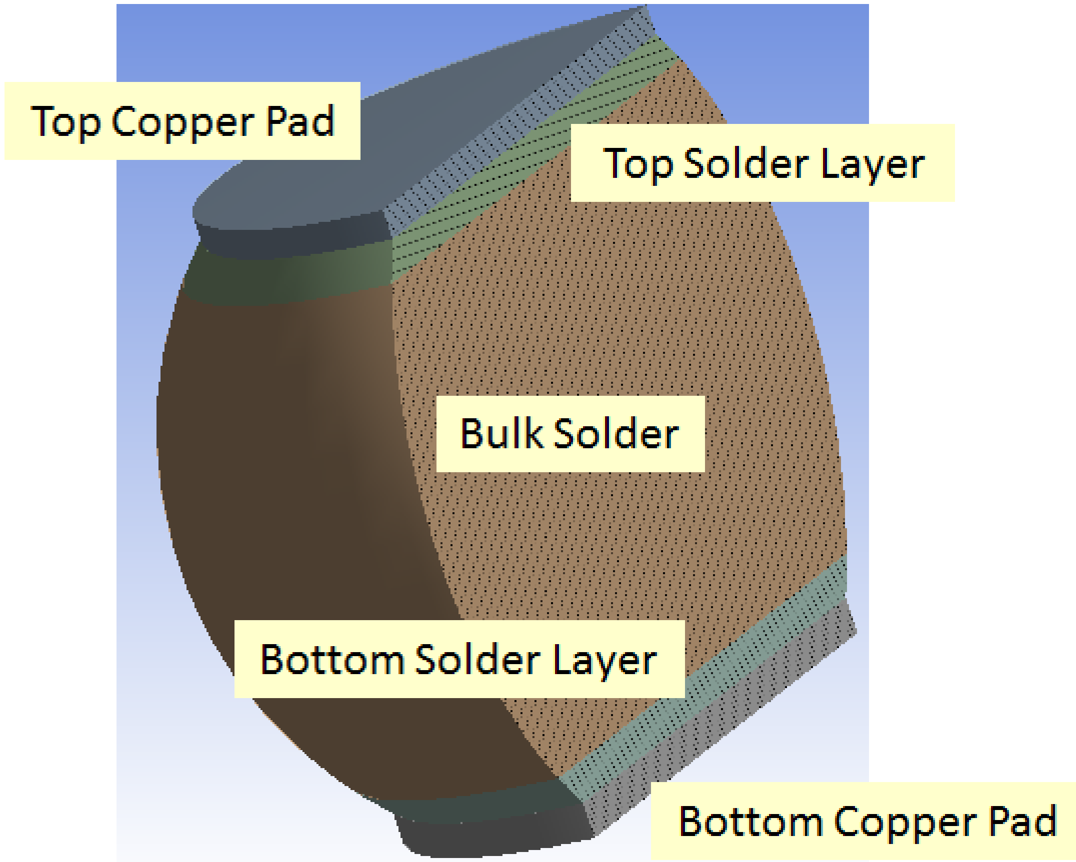


e. **"Repair>Missing Faces"** then click the green check mark



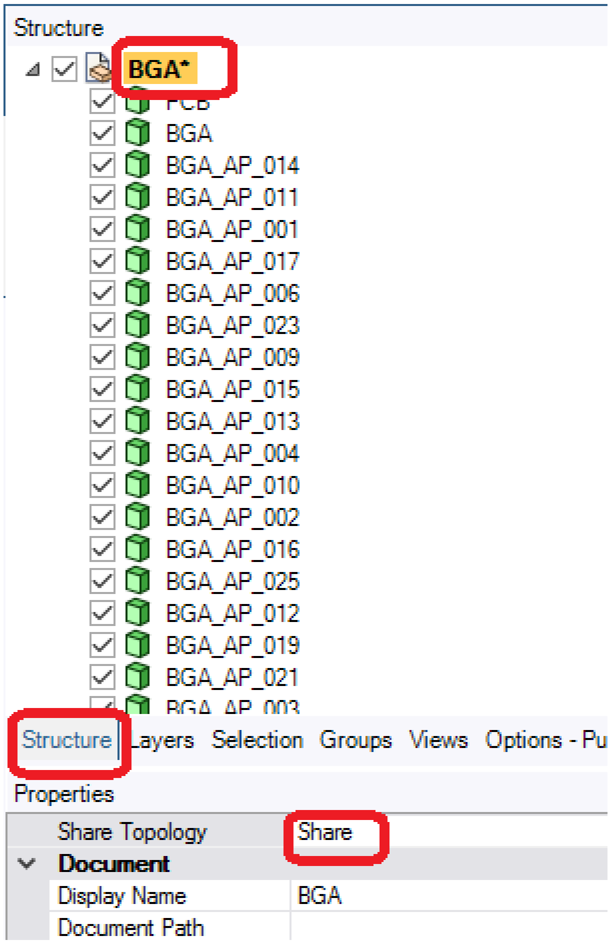
7. Modify the model geometry for the solder ball of interest

Modified Solder Joint Geometry

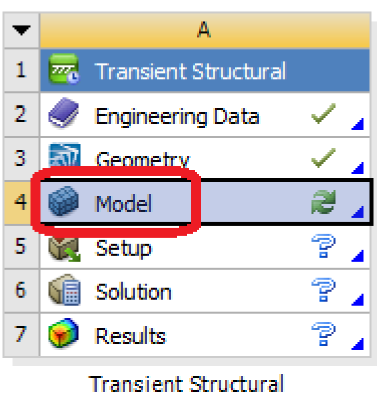


The top and bottom layers are made of solder and are used to track the damage in the top and bottom of the ball. The thickness of the solder layer should be between 10% to 20 % of the total solder thickness. The shape and mesh of the solder ball should be modeled with great care.
It is recommended to create a detailed model for the corner ball or the ball under the die corners.
The pads are made of copper.

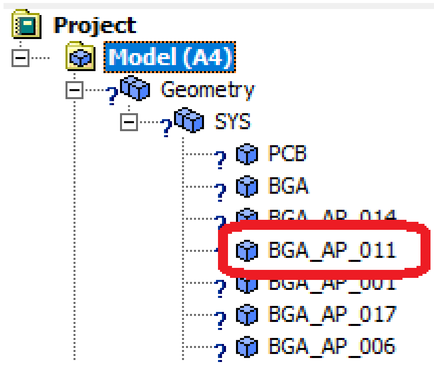
8. Select the BGA structure and **Share topology>Share**



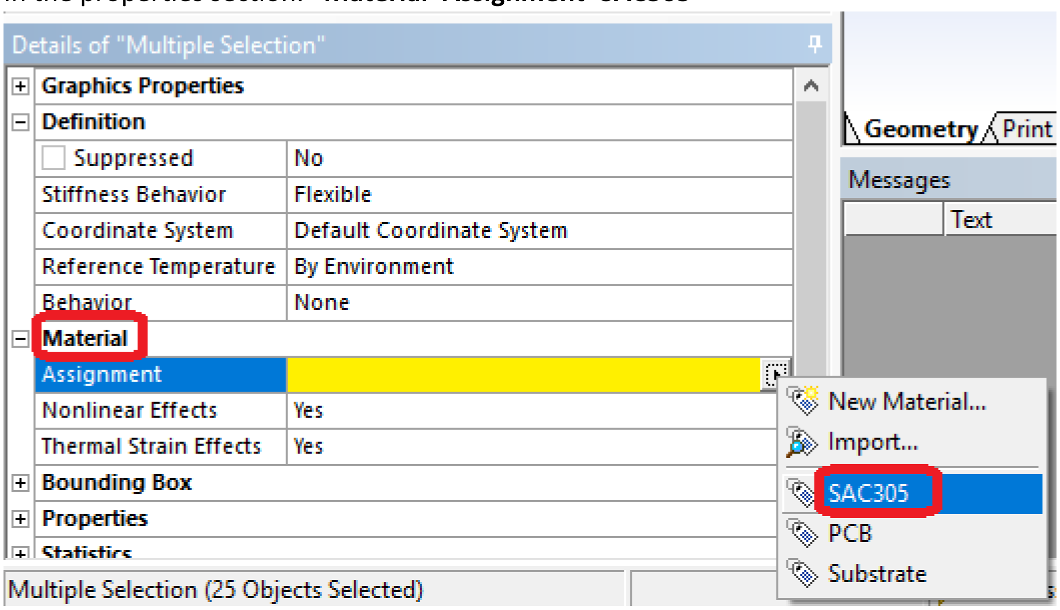
9. Exit SpaceClaim
10. Open Mechanical by double clicking **"Model"**



11. Assign the SAC305 material to the solder balls
    a. Open the Model>Geometry>SYS and select the BGA balls by using the Shift and Ctrl buttons

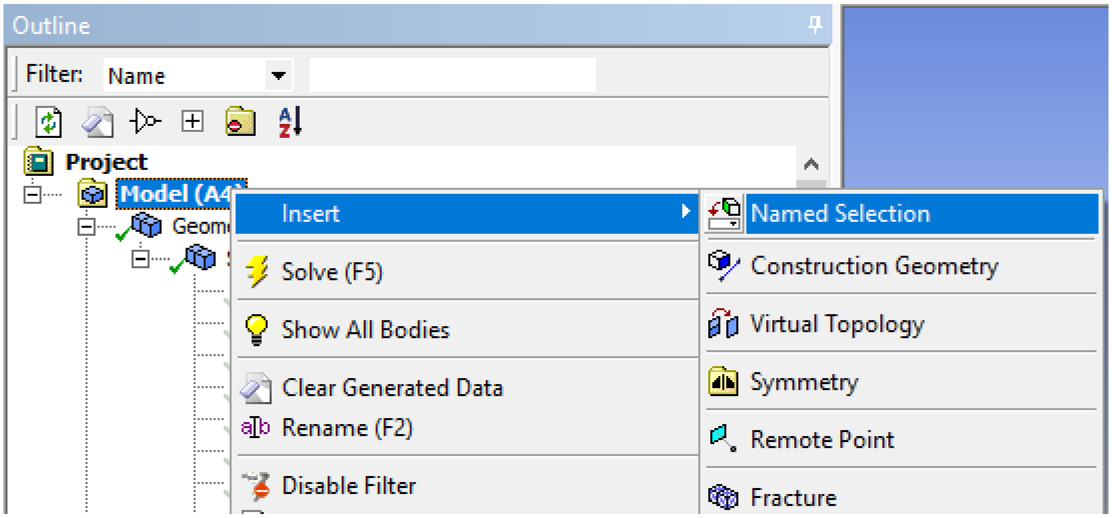


    b. In the properties section: **“Material>Assignment>SAC305”**

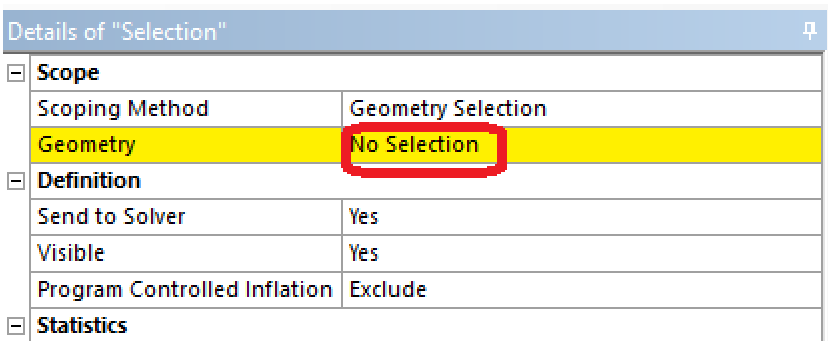


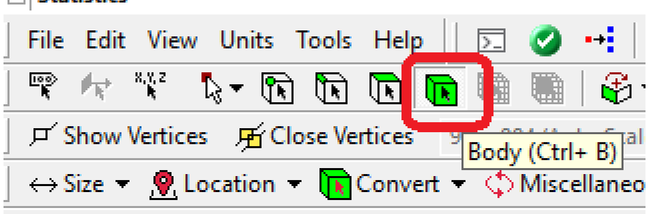
12. Assign the rest of the materials to the various body parts in a similar way

13. Create “Named Selections” and select the volumes of interest in the solder balls
    Name the selections in uppercase letters without spaces or special characters. In this example, the named selection will be called “BALL1”
    a. Right click **“Model>Insert>Named Selection”**

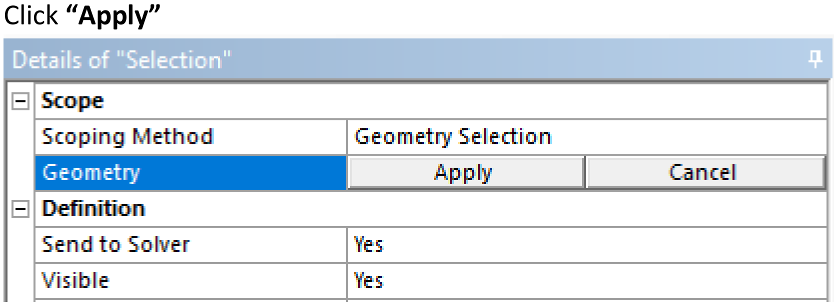


    b. Click the **“Geometry”** property and use the body selection tool to select the solder geometry of interest.





Select the solder geometry
Click **“Apply”**



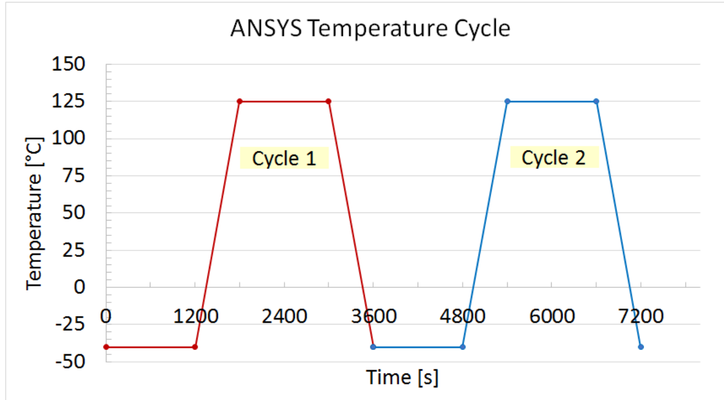
c. Right click **“Selection>Rename”** and set the name to “BALL1”

14. Repeat for any other solder volumes of interest.
    Note: it is possible to create the named selections for elements after the meshing process.
15. Set the solver unit systems and save the database file
    a. **“Analysis Settings>Analysis Data Management>Save MAPDL db>Yes”**
    b. **“Analysis Settings>Analysis Data Management>Solver Units>Manual”**
    c. **“Analysis Settings>Analysis Data Management>Solver Unit System>µmks”**

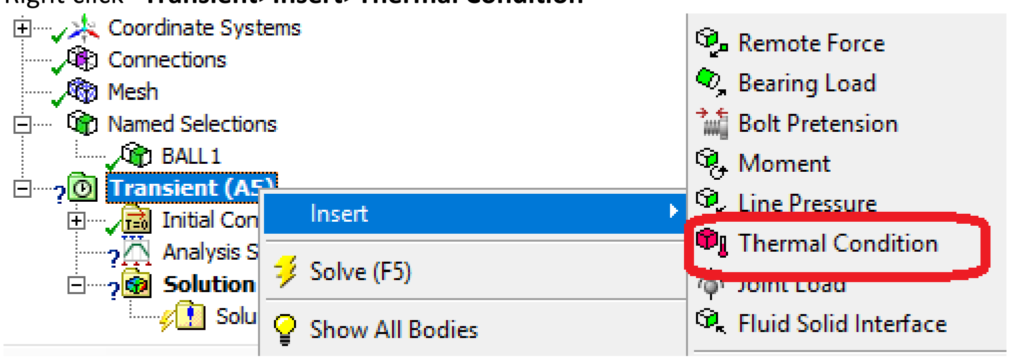
Analysis Data Management	
Solver Files Directory	C:\Users\
Future Analysis	None
Scratch Solver Files ...	C:\Users\
Save MAPDL db	Yes
Delete Unneeded Fi...	Yes
Nonlinear Solution	Yes
Solver Units	Manual
Solver Unit System	µmks

16. Create the temperature cycle and apply it to the model
    In this example the temperature cycle is a (-40)°C to 125°C cycle that takes one hour per cycle

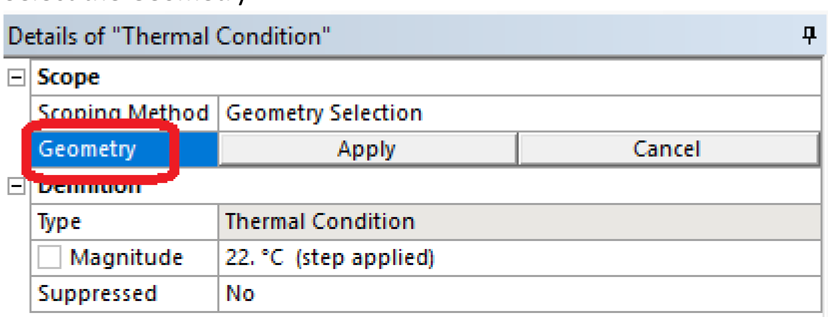
	Time [s]	Temperature [°C]
Start of Cycle 1	0	-40
	1200	-40
	1800	125
	3000	125
Start of Cycle 2	3600	-40
	4800	-40
	5400	125
	6600	125
End of Cycle 2	7200	-40



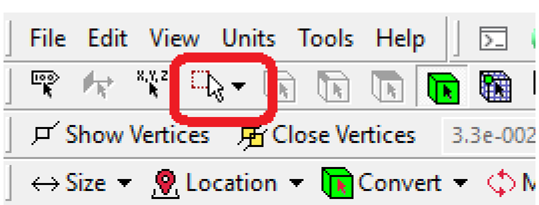
a. Right click **"Transient>Insert>Thermal Condition"**



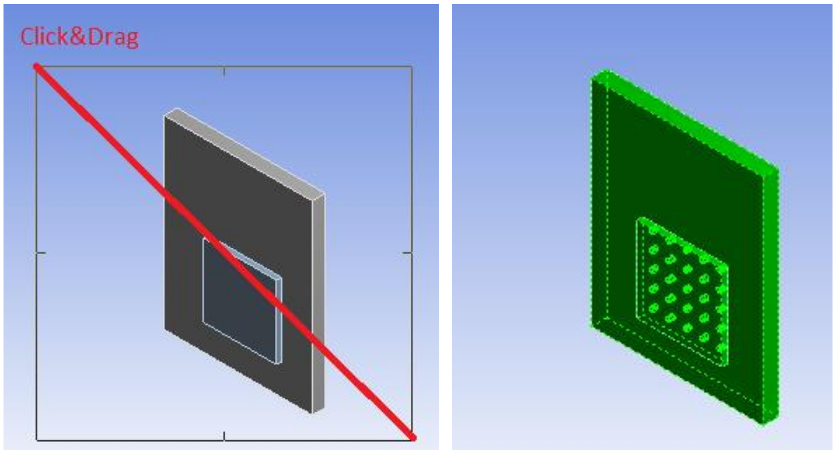
b. Select the Geometry



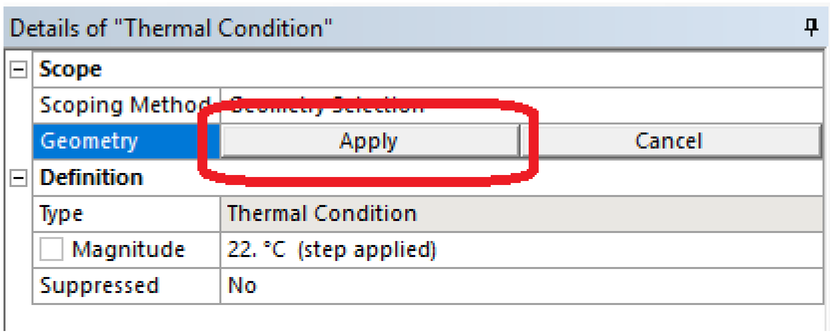
Use the box selection tool to select the whole model



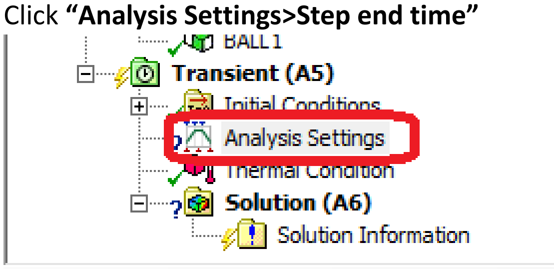
Click and drag to make a box around all the geometry

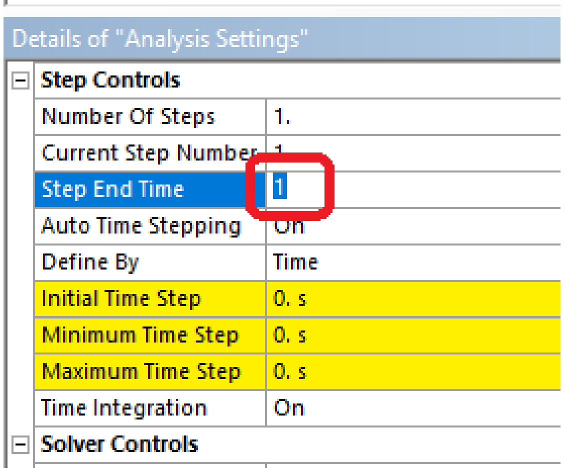


Click **"Apply"**



c. Click **"Analysis Settings>Step end time"**





d. Enter the "Step End Time", "Initial Time Step", "Minimum Time Step" and "Maximum Time Step"

Details of "Analysis Settings"	
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1200. s
Auto Time Stepping	On
Define By	Time
Initial Time Step	300. s
Minimum Time Step	100. s
Maximum Time Step	600. s

e. Change the number of steps to "2". Change the current step number to "2"
Enter the "Step End Time", "Initial Time Step", "Minimum Time Step" and "Maximum Time Step"

Step Controls	
Number Of Steps	2.
Current Step Number	2.
Step End Time	1800. s
Auto Time Stepping	On
Define By	Time
Carry Over Time Step	Off
Initial Time Step	300. s
Minimum Time Step	100. s
Maximum Time Step	600. s

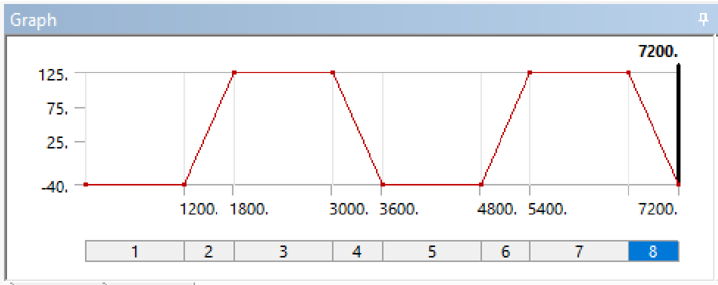
Note: The "Step End Time" is set by the temperature cycle but the time steps are adjusted for convergence. Be aware that some load and geometry combinations will need different settings than the ones used in this example.

f. Repeat until all eight steps are defined

Tabular Data

	Steps	End Time [s]
1	1	1200.
2	2	1800.
3	3	3000.
4	4	3600.
5	5	4800.
6	6	5400.
7	7	6600.
8	8	7200.
*		

g. Click **“Thermal Condition”**
Enter the temperature profile in the **“Tabular Data”**



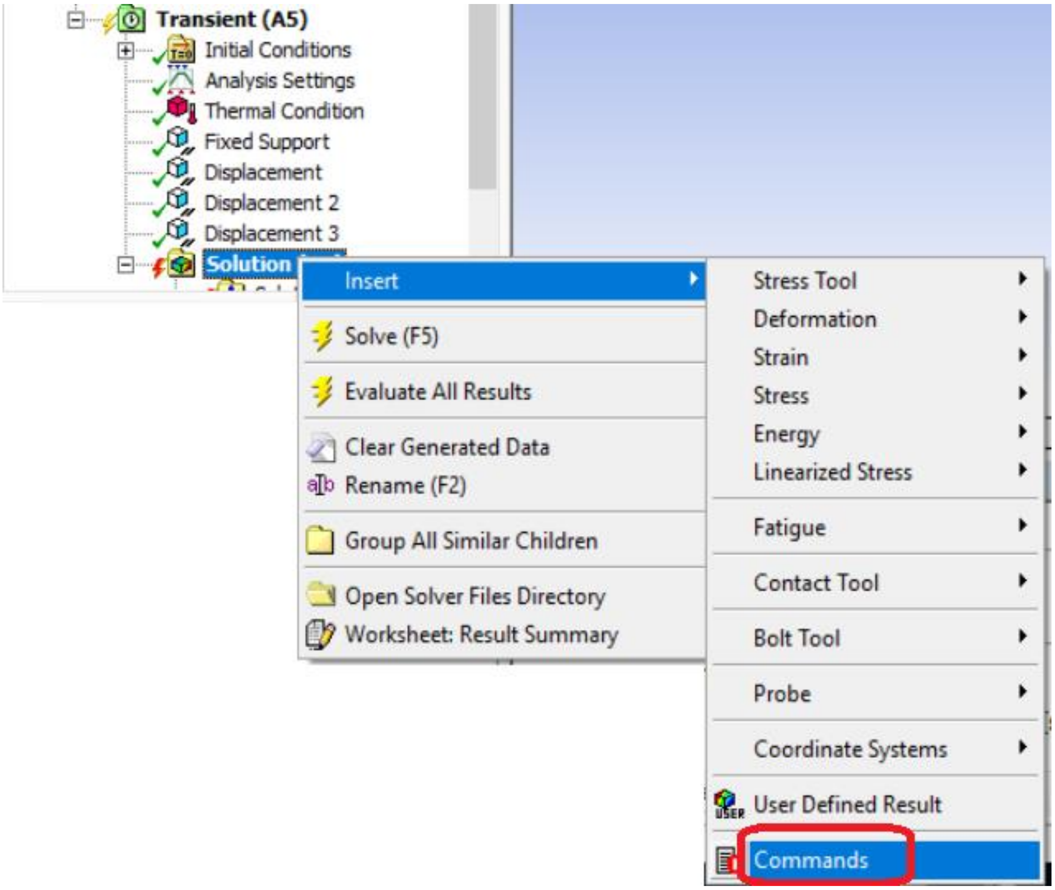
Tabular Data

	Steps	Time [s]	Temperature [°C]
1	1	0.	-40.
2	1	1200.	-40.
3	2	1800.	125.
4	3	3000.	125.
5	4	3600.	-40.
6	5	4800.	-40.
7	6	5400.	125.
8	7	6600.	125.
9	8	7200.	-40.

h. More than two temperature cycles may be desired in some cases. Use the above procedure to create as many cycles as needed.

17. Create the appropriate boundary conditions:
    Note: The boundary conditions depend on the type of model. Quarter symmetry models have a different boundary condition than the supports in this example.

18. Insert the strain energy density calculation commands
    a. Right click **“Solution>Insert>Commands”**



    b. In the commands windows insert the following script
    Script was adapted from "Finite Element Based Solder Joint Fatigue Life Predictions for a Same Die Stacked Chip Scale Ball Grid Array Package". By: Bret A. Zahn, ChipPAC Inc.
    http://ansys.net/papers/nonlinear/finite_element_based_solder_joint_fatigue.pdf

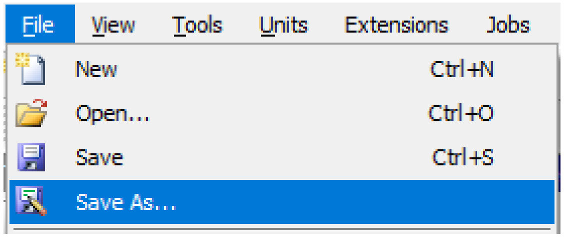
```
1  /post1
2  allsel,all
3  cmsel,s,BALL1,elem !SELECT ELEMENTS FROM NAMED SELECTION
4  !############################################
5  ! CALCULATE AVERAGE PLASTIC WORK FOR CYCLE 1
6  subset,4,last,1 ! SELECT THE END OF CYCLE 1 (CHANGE “4”)
7  etable,vtable,volu
8  etable,vsetable,nl,plwk
9  smult,pwtable,vtable,vsetable
10 ssum
11 *get,sumplwk,ssum,,item,pwtable
12 *get,sumvolu,ssum,,item,vtable
13 wavg1=sumplwk/sumvolu
14 !############################################
15 ! CALCULATE AVERAGE PLASTIC WORK FOR CYCLE 2
16 subset,8,last,1 ! SELECT THE END OF CYCLE 1 (CHANGE “4”)
17 etable,vtable,volu
18 etable,vsetable,nl,plwk
19 smult,pwtable,vtable,vsetable
20 ssum
21 *get,sumplwk,ssum,,item,pwtable
22 *get,sumvolu,ssum,,item,vtable
23 wavg2=sumplwk/sumvolu
24 !############################################
25 ! CALC DELTA AVERAGE PLASTIC WORK
26 dwavg=wavg2-wavg1
```

The “CMSEL command in line 3 has the **“Named Selection”** called **BALL1** that was created to select the solder volume of interest. Similar code snippets can be added for each solder volume of interest.

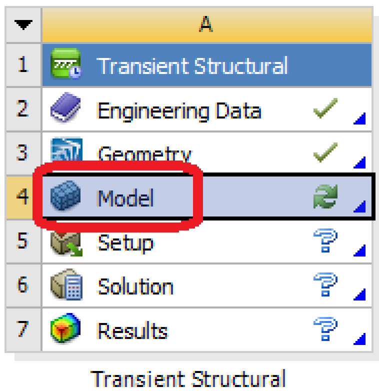
The subset command in line 6 selects the load step for the end of cycle 1 **(subset,4,last,1)** as defined before. The command in line 16 selects the end of the second cycle **(subset,8,last,1)**. The numbers “4” and “8” correspond to the definition of the temperature cycle and need to be adjusted accordingly.

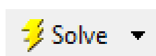
This “Commands” file can be downloaded from:
https://ia601508.us.archive.org/21/items/Commands/Commands.txt

19. Save your model. Close “Mechanical” and save the model in the main project window

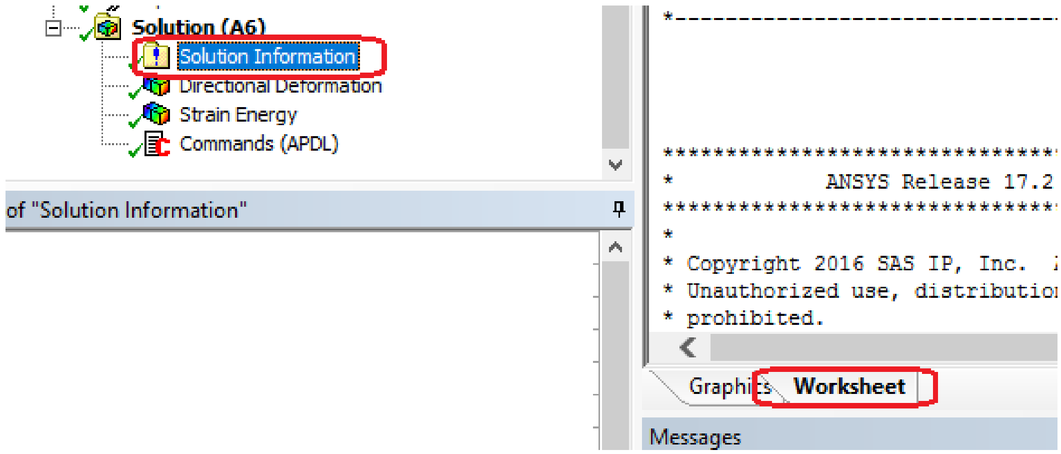


Re-open mechanical by double clicking the **“Model”**

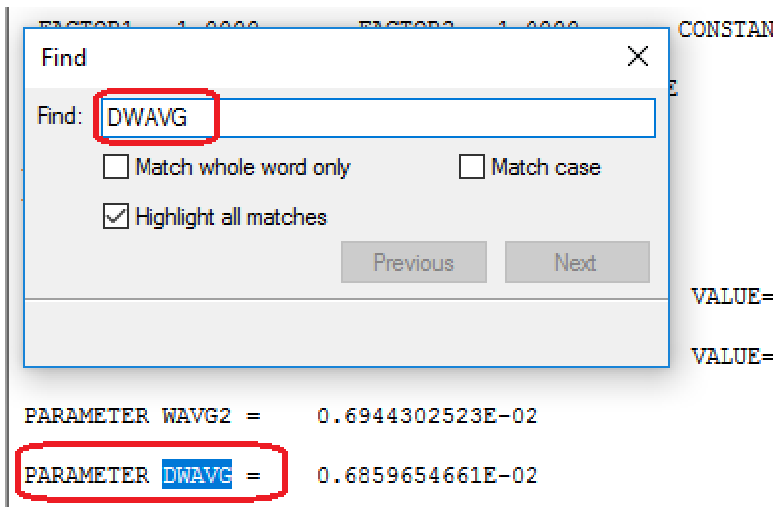


20. Click solve. 

21. Calculate the number of cycles to failure from the result:
    a. Click **"Solution>Solution Information>Worksheet"**



    b. Press **"CTRL+F"**
    c. Enter **"DWAVG"** in the "Find" window



    d. The **DWAVG** value for SAC305 can be inserted to the equation as "w_{aac}" on page 28 of: http://ansys.net/ansys/papers/asyed_ectc2004_corrected.pdf
    e. In the example above this would be
       Nf = 1/(0.0019*DWAVG)
    f. This equation calculates the number of cycles to failure for BGA solder joints loaded in fully reversed shear load due to temperature cycling. The calculation should give a number for cycles to failure for the whole element set in the report. The selection of the named selection is important and can have an effect on the results.

DISCLAIMER

DfR represents that a reasonable effort has been made to ensure the accuracy and reliability of the information within. However, DfR Solutions makes no warranty, both express and implied, concerning the content of this report, including, but not limited to the existence of any latent or patent defects, merchantability, and/or fitness for a particular use. The contents of this report and the observations and conclusions made by DfR are not intended to be comprehensive or exhaustive. DfR has used industry standard practices in preparing this report and has made assumptions it views as reasonable in reaching the conclusions contained herein. Reasonable experts' observations and conclusions may differ after conducting a similar review and other factors not considered by DfR or present at the time of DfR's review could impact such experts' findings. While DfR recognizes that this report will help guide the evaluation of the device or product, DfR will not be liable for loss of use, revenue, profit, or any special, incidental, or consequential damages arising out of, connected with, or resulting from, the information presented within this report.